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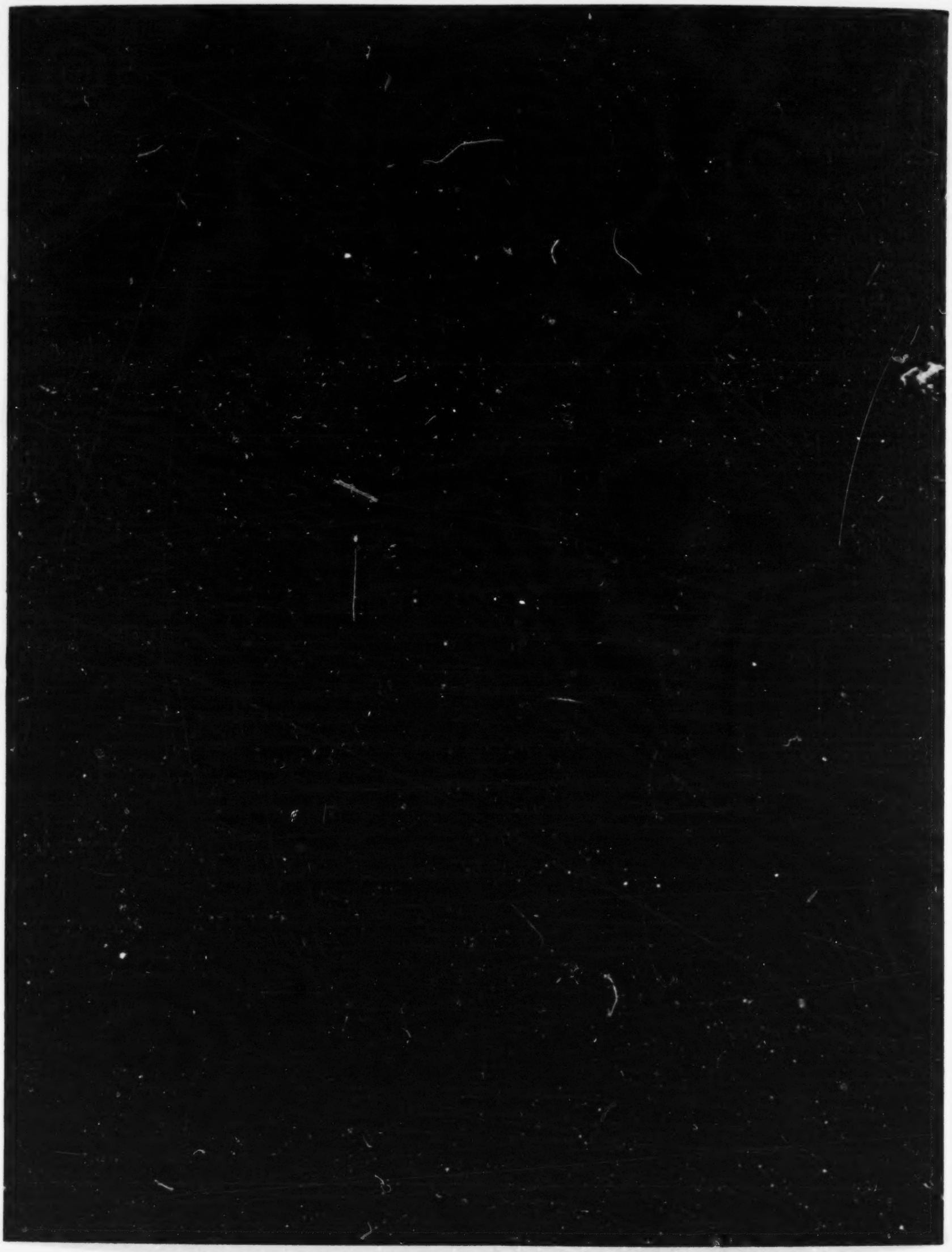

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COMBUSTION POWER UNIT – 400

CPU-400

A technical abstract

Prepared by the Staff of
Combustion Power Company, Inc., Palo Alto, California

for the

Bureau of Solid Waste Management

Reporting Work Done Under Contract No. Ph 86-67-259

U. S. Department of Health, Education, and Welfare

Public Health Service

Consumer Protection and Environmental Health Service
Environmental Control Administration

Bureau of Solid Waste Management
Rockville, Maryland

1969

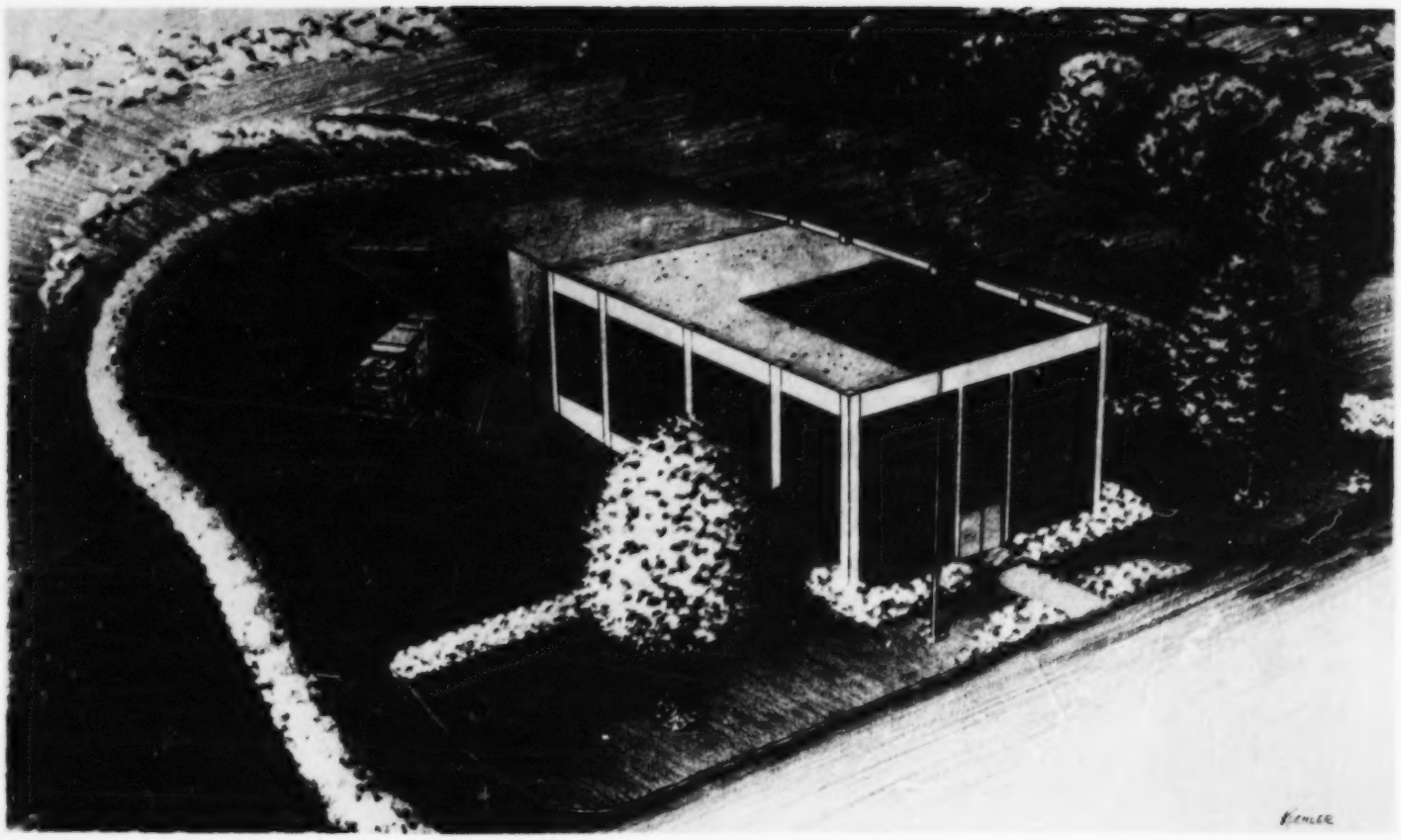

Figure 1.

Aerospace technology may have led to a unique basic unit for processing solid wastes and controlling pollution. Being developed by Combustion Power Company, Inc., Palo Alto, California, under contract with the U.S. Public Health Service, the Combustion Power Unit-400 (CPU-400) is designed as a turboelectric generator plant that will use municipal solid wastes as fuel. The baseline configuration is a modular unit that is designed to utilize 400 tons of refuse per day (the amount of solid wastes generated by a community of 150- to 200-thousand population). These 400 tons of refuse will produce up to 15,000 kilowatts of electric power. Income from the sale of the electric power generated by this system may permit a substantial reduction in the cost of solid waste disposal.

Currently the CPU-400 is in the early development phase. Experimental tests are being conducted on subscale hardware. A working 1/10th-scale model of the system is scheduled for testing early in 1970, and a full-scale prototype is planned for operation in 1972. This is being supported by funding provided by the Solid Waste Disposal Act of 1965.

Using either available energy or by-products from the combustion process, add-on systems to the basic CPU-400 may provide: (1) automated vacuum collection of refuse, (2) fresh water produced from saline or brackish water, (3) centralized steam for commercial heating and air conditioning, (4) incineration of sewage sludge.

Though primarily designed as an economic, pollution-free method of disposing of the ever increasing amounts of solid waste now plaguing our urban areas, CPU-400 modular units, operating as baseload electric power generating stations near the load centers, could be conveniently located to supplement power supplied by local utilities. It is anticipated that the units would be capable of supplying as much as 10 percent of an average community's electric power requirements.

The system uses solid waste as fuel, a surprisingly good energy source. The material is burned in a high-pressure combustor to produce hot gases that are used to power a gas turbine. In turn, the turbine drives a 15,000-kilowatt electric generator. Income from the sale of this electric power may be used to offset the cost of operation of the plant. Thus, it is possible that the basic CPU-400 may dispose of refuse for as little as 95 cents per ton, a fraction of normal incineration cost.

Conventional incinerators burn at atmospheric pressure resulting in large, sprawling installations. The Düsseldorf incinerator, a representative example of modern European waterwalled incinerators (shown scaled to the same capacity of the CPU-400), is many times larger (Figure 2). Since the units are expected to be clean, compact, and quiet, they might be dispersed about a city to substantially reduce hauling costs.

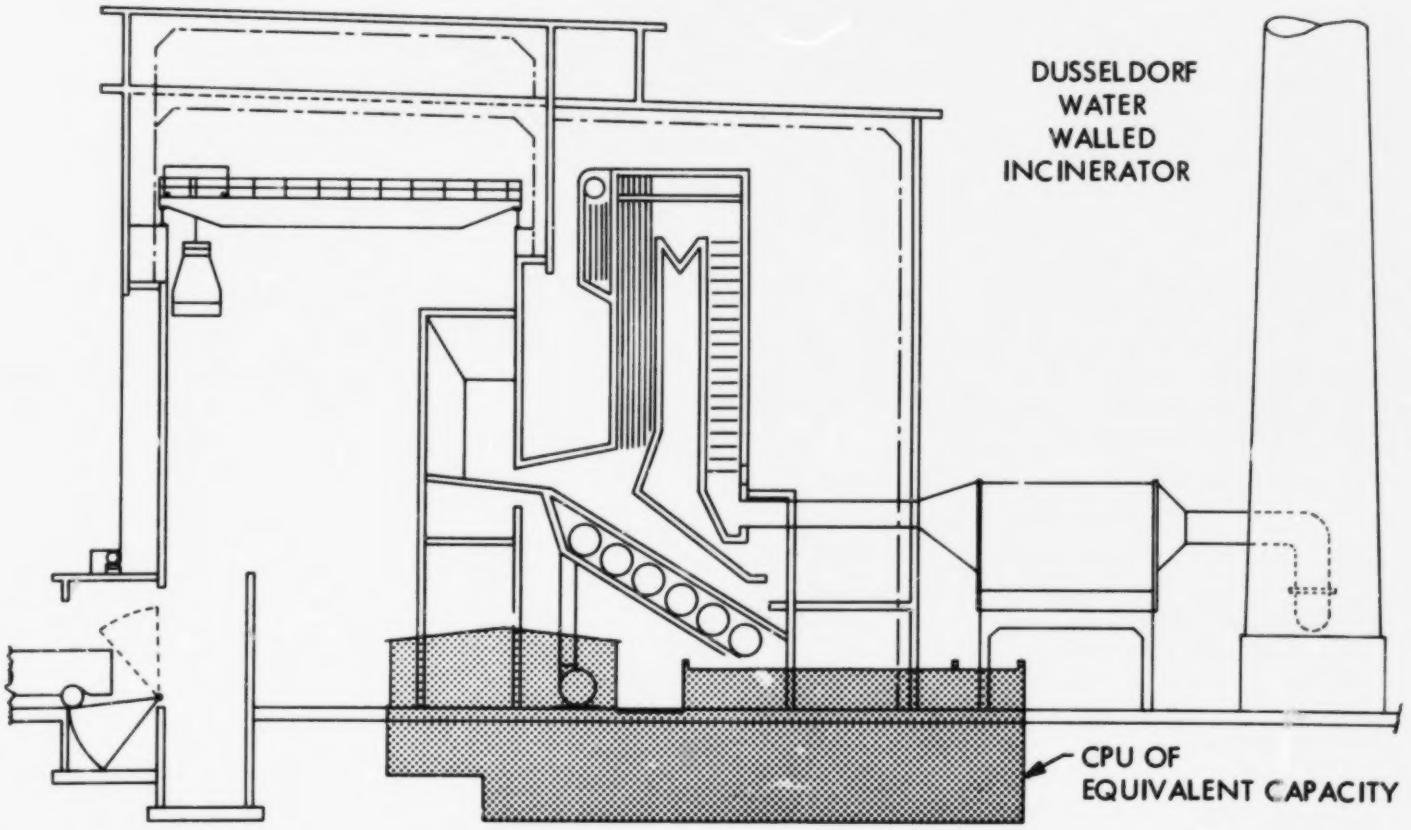

Figure 2. The Düsseldorf incinerator, a representative example of modern European waterwalled incinerators, is many times larger than the CPU-400; they are shown scaled to the same capacity.

PROCESS DESCRIPTION

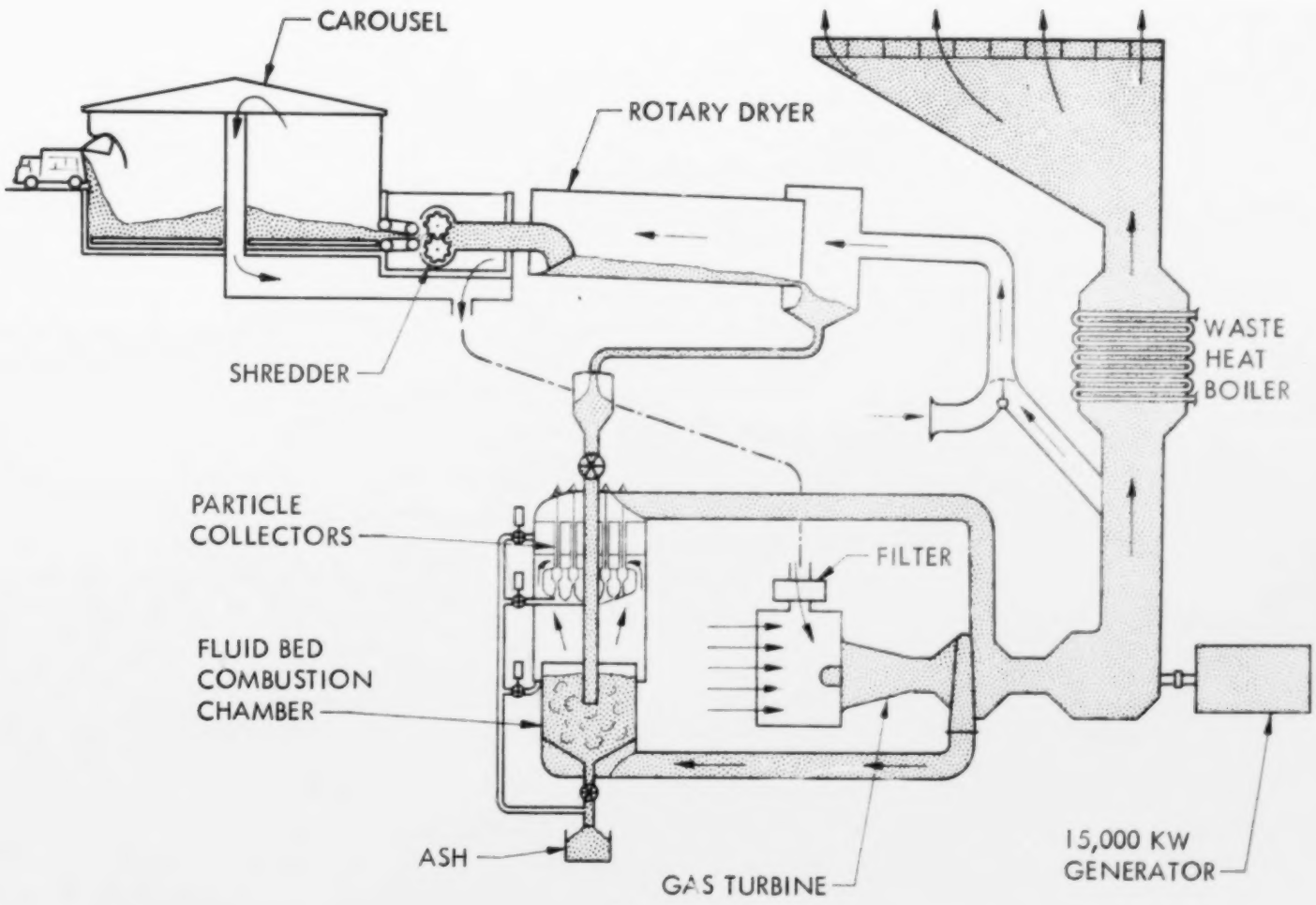

Figure 3.

The solid waste handling and preparation in the CPU-400 system will be automatic. No prior separation is anticipated. Material from municipal collection trucks will be dumped into a storage area, the "carousel", which is circular and will rotate to feed the solid waste into the shredder. The need for cranes and associated high-bay construction should be eliminated. The carousel will hold enough solid waste to operate the unit for 30 hours and provides a large effective tipping area for the trucks.

Leaving the carousel, the solid waste will be shredded in one of two shredders. It will be subsequently dried using heat from the turbine exhaust gas; drying increases the burning rate and makes the burning rate more uniform by reducing the highly variable moisture content. Clean combustion in a more compact combustion chamber should result.

To prevent dust and odors from escaping to the environment, the gas turbine will draw compressor intake air from the carousel, shredders, and dryer. The dust will be collected upstream of the compressor by air filters.

Shredded, dried, and mixed solid waste will be transported and injected into the combustor, which will be supplied 100 psia, 584° F air from the compressor. A fluid bed combustion reactor is planned for the CPU-400. In this reactor, inert material is suspended or "fluidized" by the air from the compressor passing through the chamber. It is anticipated that retention characteristics and scrubbing action of the fluid bed will produce heat transfer rates 5 to 10 times higher than conventional grate burners.

Removal of the particulate matter from the combustion gases is accomplished upstream of the turbine. The particle collectors combine an inertial separator followed by an electrostatic precipitator (Figure 3). Also being developed for possible use in the CPU-400 is an alternate particle collector design employing a continuously cleaned, deep-bed, fibrous mat filter.

The clean, hot gas leaving the particle collectors is expanded through the gas turbine, which drives the compressor and the electric generator, producing 15,000 kilowatts of electric power. The exhaust gas leaving the turbine is near atmospheric pressure at a temperature of 930° F. A portion of the heat of the exhaust gas is used for drying the incoming material.

GAS TURBINE POWER GENERATION. Electric power is a readily marketable by-product of solid waste disposal in most areas. Consumed in every city in the country, the market is stable, the price is stable, and the market is growing at approximately 7 percent per year. Three types of equipment are commonly used to generate electric power using combustion processes: steam turbine generators, gas turbine generators, and diesel or gas engine generators. Each type is best suited to a specific range of capacity (Figure 4).

Steam turbine generators dominate the larger sizes and provide almost the entire power needs of the nation. In the smallest sizes, the diesel or gas engine generators have been most used but are receiving vigorous competition from small gas turbines. In the mid-range, the range where an optimum-sized incinerator would fall (200 to 800 tons per day), the gas turbine is dominant.

Gas turbines are favored in the range of interest because they are simple, compact, and highly automated. Thermodynamically, gas turbines are slightly less efficient than steam turbines, but the steam turbines are only efficient in sizes larger than are optimum for incinerators. The principal disadvantage of the gas turbine in the past has been its requirement for high-cost fuel (oil or gas); that disadvantage will be eliminated in the case of the CPU-400, which will operate on solid waste.

The use of the gas turbine also opens many avenues for add-on systems to provide additional services for the community over and above refuse disposal. The CPU-400 will use approximately one-fourth of the heat of burning solid waste to produce electric power (typical of the gas turbine cycle) which leaves a substantial quantity for the other add-on systems. Also it can produce the vacuum for the automated refuse collection system.

Since several gas turbines are available in the 15-megawatt capacity, this size was selected for the CPU-400.

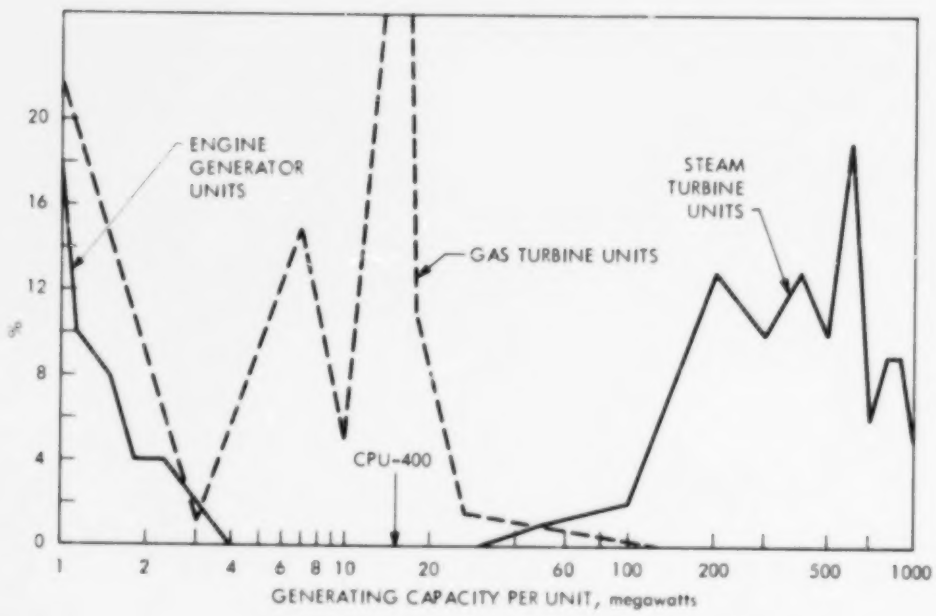

Figure 4.

PLANT LAYOUT

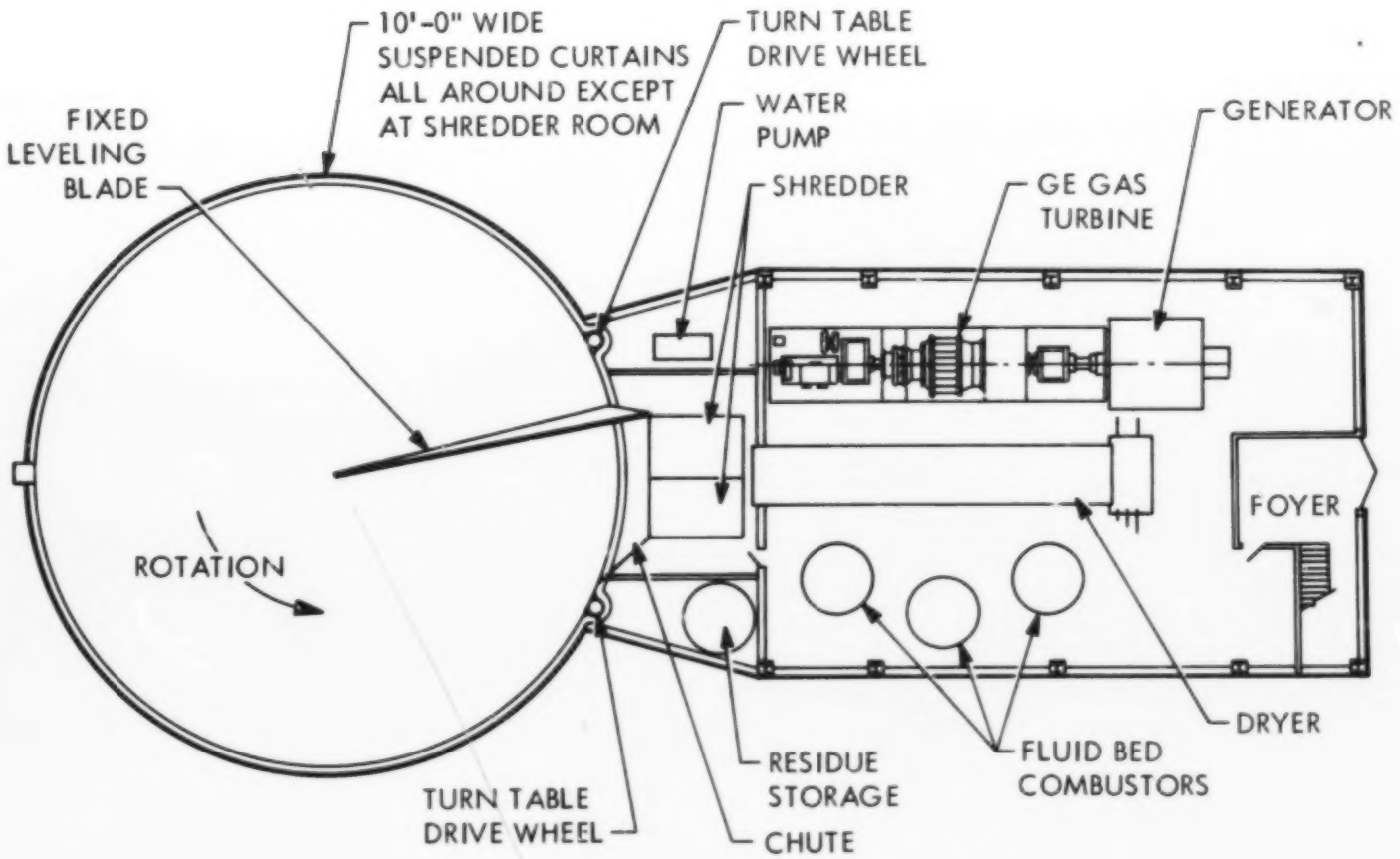

Figure 5.

In a proposed layout of a CPU-400 plant the carousel is placed to the rear of the building, away from the street. Two shredders are provided, since they will require high maintenance compared to other components in the system; they will be housed in soundproof enclosures between the carousel and the main building. Refuse will be automatically fed from the carousel through the shredders and into the dryer.

Three combustion chambers will be employed, each sized to 50 percent of plant capacity and measuring 10 feet in diameter by approximately 25 feet high. Normal plant base-load capacity can be maintained with two of the three chambers in operation.

Residue will be automatically transported from the combustion chamber and stored in hoppers for periodic removal. An air-conditioned fully automated control room is provided at the front of the plant; from there, soundproof windows will afford a broad view of the plant interior.

Trucks will be weighed and identified prior to being admitted to the tipping area. A remote television camera allows the operator in the control room to visually inspect the truck.

Architecturally attractive and free from dust, odors, smoke, and noise, the CPU-400 might be located in existing residential or light industrial areas of many cities. Other possible sites might include existing city property in downtown areas, utility-owned property adjacent to a substation, or old incinerator sites.

MAJOR COMPONENTS

REFUSE CAROUSEL. The carousel is designed with a cylindrical solid waste storage volume 15 feet deep and 80 feet inside diameter providing a storage capacity for 2800 cubic yards of material. At an average density of 314 lb per cu yd, this is equivalent to 438 tons of municipal waste, sufficient for 30 hours of operation at rated capacity. Storage capacity may be increased by providing more depth in the carousel.

The carousel will be completely sheltered. Glass cloth panels, which permit continuous flow of air into the carousel, will be suspended around the periphery of the roof. The lightweight panels may be easily deflected by the trucks dumping into the pit.

The turntable on which the solid waste rests is designed as a segmented or compartmentalized barge, floating on water; it will rotate continuously and can be raised or lowered by changing the water level. In this way, the refuse may be automatically fed into the shredder.

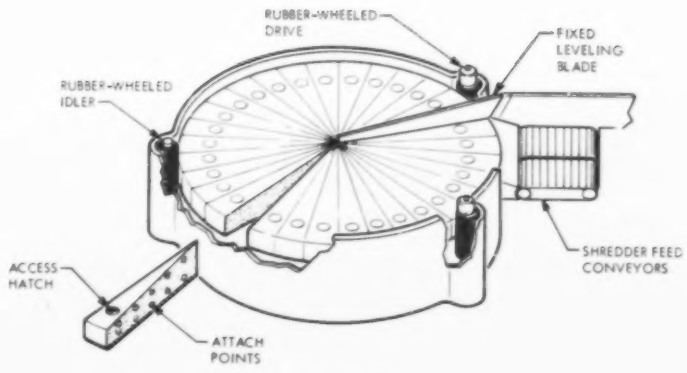

Figure 6.

SHREDDER. Several shredders, suitable for CPU-400, are now being developed by private manufacturers. One such machine is illustrated in Figure 7. Refuse shredders are designed to shred such diverse items as tin cans, oil drums, railroad ties, and tires, as well as paper, cardboard, and plastics.

The shredder presently selected is a 300-hp machine with a rated capacity of 20 tons per hour. It has both a low-speed shearing and a high-speed chopping action.

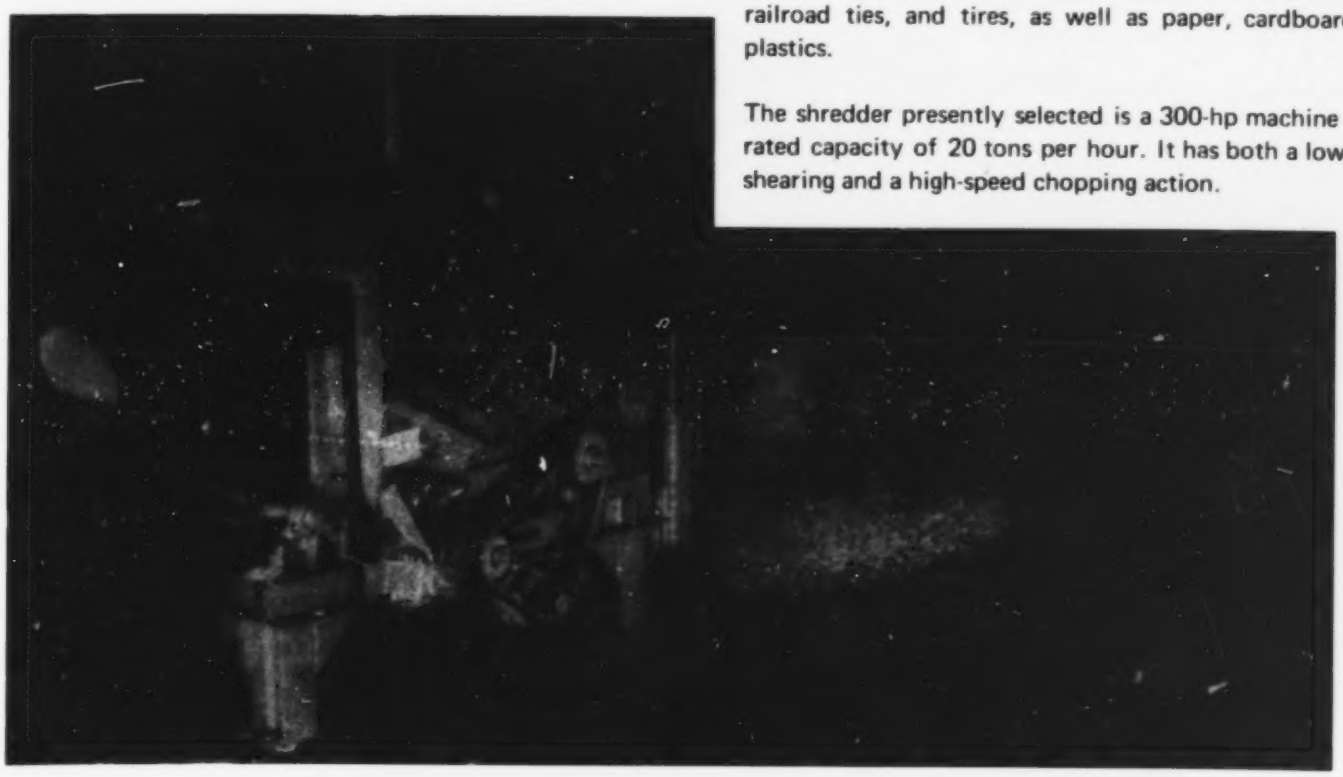

Figure 7.

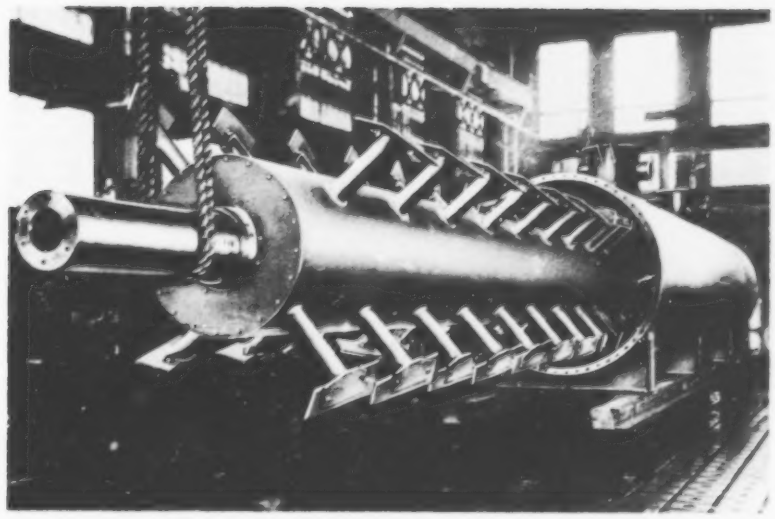

Figure 8.

REFUSE DRYER. The stainless steel dryer is designed to be 8 feet in diameter and 50 feet long. An internal agitator will promote rapid and uniform drying and provide blending and mixing of the solid waste material.

Hot exhaust gases will be drawn through the dryer by a fan and pass through the shredders and the carousel area before recirculation through the compressor. Optimum drying should be achieved by controlling the temperature of the gases leaving the dryer to the 212° F to 250° F range.

AIRLOCK-FEED. The dried, shredded solid waste will be transported pneumatically from the dryer to the airlock-feed for injection into the combustion chamber. The airlock-feed is designed to provide continuous transfer of the material without overheating. The star wheel has the capability of cutting or shearing any object that might block the rotor. Compressor bleed air will be used for cooling and rotor pocket purging.

If jamming should occur in the star wheel, however, the direction of rotation may be momentarily reversed, thus giving the offending object a chance to fall into a pocket.

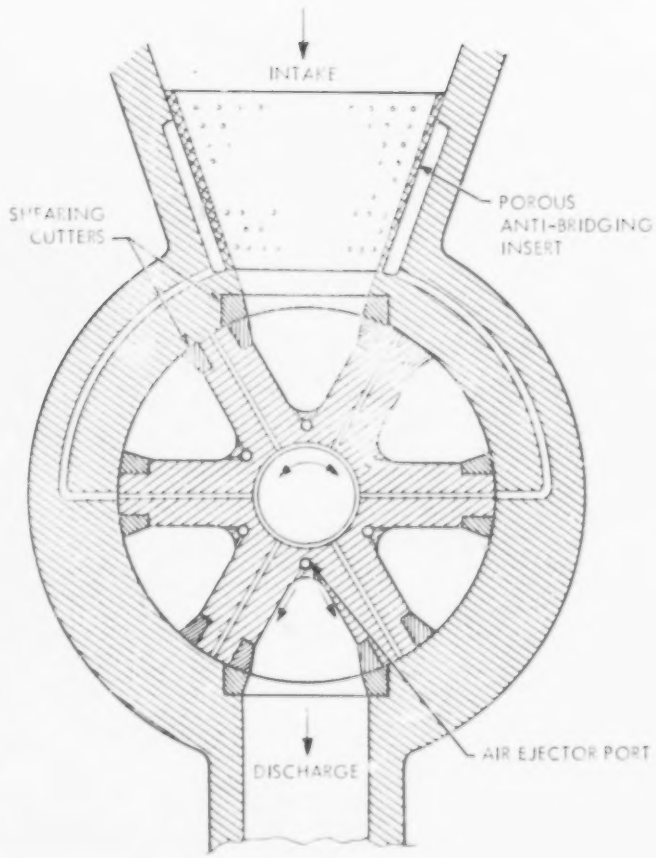

Figure 9.

REFUSE COMBUSTOR. The CPU-400 is designed to use a fluid bed reactor, a relatively new approach to the design of high heat release combustors. The fluidized bed will be formed by blowing the primary air through inert particles, which can withstand high temperatures without slagging. By careful selection of the particle characteristics and control of the air flow to support the bed without sweeping the particles out of the chamber, a "fluidized" state should be maintained such that the dynamic characteristics are analogous to that of a boiling liquid.

The solid waste fuel will be introduced into the center of the fluidized bed; this promotes dispersion, causes rapid rise to ignition temperature, and maintains residence time sufficient for combustion of all burnable particles in the reactor. Burning rate will be high because the material will be in direct contact with the hot inert bed particles, charred surfaces will be continuously abraded away, and rapid gas mixing will occur, enhancing the completeness and rate of the gas-phase reaction.

Most of the ash will be carried off with the gases leaving the fluid bed surface and will be subsequently collected in the particle collectors. The ash particles, which are larger or more dense than the inert particles forming the bed, will eventually reach the apex at the bottom of the chamber where they are to be removed through the rotary air-lock.

In addition to its high heat release per unit volume, the reactor appears to have a significant advantage over conventional incinerators in its ability to control noxious gas emission. The low uniform temperature of the bed (1,500° F to 1,650° F) should limit the formation of oxides of nitrogen. Selection of the bed material coupled with its inherent mixing characteristics should control the formation of oxides of sulfur and of hydrogen halides, primarily HCl. The highly stirred, oxygen-rich environment of the bed should be ideal for prevention of carbon monoxide and unburnt hydrocarbon emission. The total residence time in the combustor at temperatures of 1,650° F is estimated to be 1 second, in an effort to eliminate all odors by oxidation.

The design of the combustor and the selection of materials for its construction will emphasize long life in the high temperature, corrosive environment of the combustor. This environment will be restricted to the combustion chamber and particle collectors by design, prohibiting the corrosive elements from entering the turbine. Replaceable liners will be used for maintenance; these liners will be independent of the basic pressure vessel.

An alternate combustor design, also using the fluid bed reactor, but employing the pyrolysis process, is being investigated for the CPU-400 system. Prototype design selections will be made at a later date.

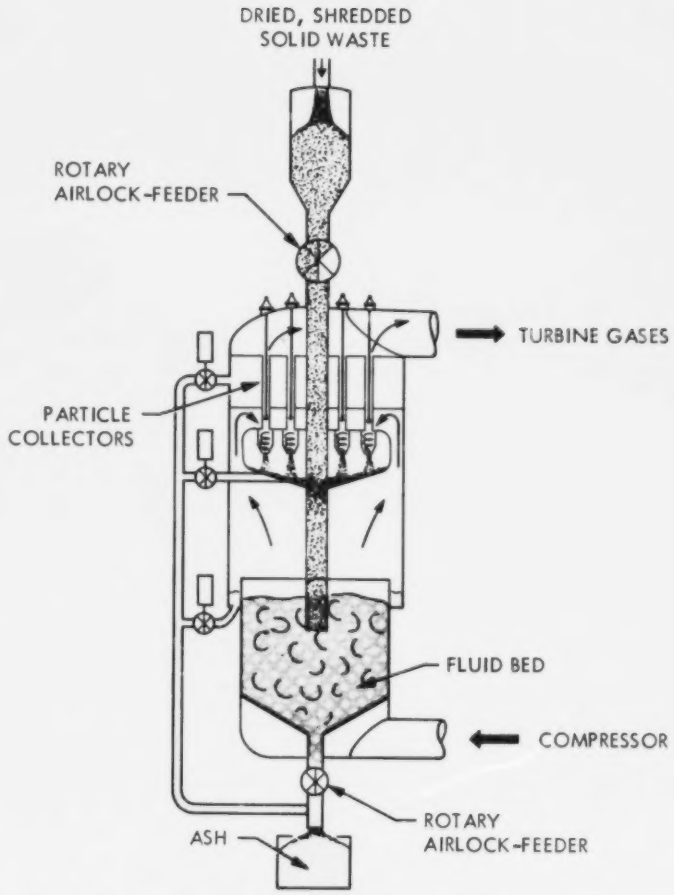

Figure 10.

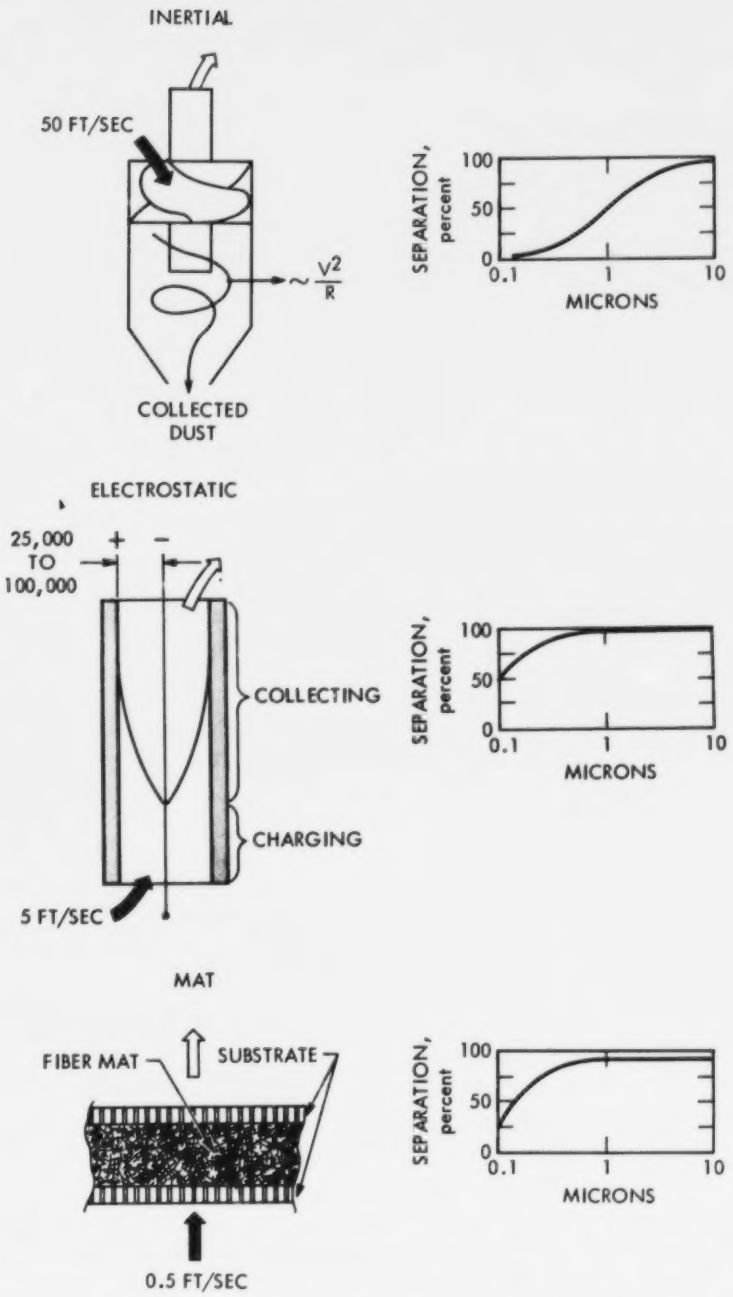

Figure 11.

PARTICLE SEPARATORS. The primary combustor design will have a two-stage particle collector packaged with the fluid bed reactor (Figure 10). The first collection stage will consist of an inertial separator; it will discharge directly into a second-st electrostatic precipitator. An arrangement of this type is being considered for the CPU-400; however, three basic collector concepts are being developed and the selection of the best combinations will be made. The high-temperature, high-pressure particle collector developments include inertial separators, electrostatic precipitators, and ceramic mat filters.

The ability to remove the particulate matter from the combustion gases is vital to the CPU-400 operation. In addition to meeting air pollution regulations, particulate removal is necessary to prevent turbine erosion. Turbines have, in the past, been operated over long periods with dusty gas cleaned by several stages of simple inertial separators.

Inertial separators use centrifugal force to separate particles from the gas stream. Recent advances have demonstrated efficiencies of 97.8 percent and greater for particles as small as 10 microns (1 micron equals 4/100,000 inch). Their performance is little affected by temperature.

Electrostatic precipitators have efficiencies over a broad range of particle size. They also have low-pressure drops. However, commonly used precipitators are generally restricted to temperatures of about 700° F, though experimental models have operated at 1,350° F. Laboratory tests will be conducted to confirm operation at 1,650° F at elevated pressure, the CPU-400 conditions.

Filters are becoming increasingly popular for particle collection because they have efficiencies over 99 percent and are low cost. Filters constructed from long staple ceramic fiber blankets have been successfully used in the chemical processing industry at temperatures of 1,000° F to 2,300° F. These high temperature filters look particularly advantageous for the CPU-400 application.

Typical Installation of a large gas turbine.

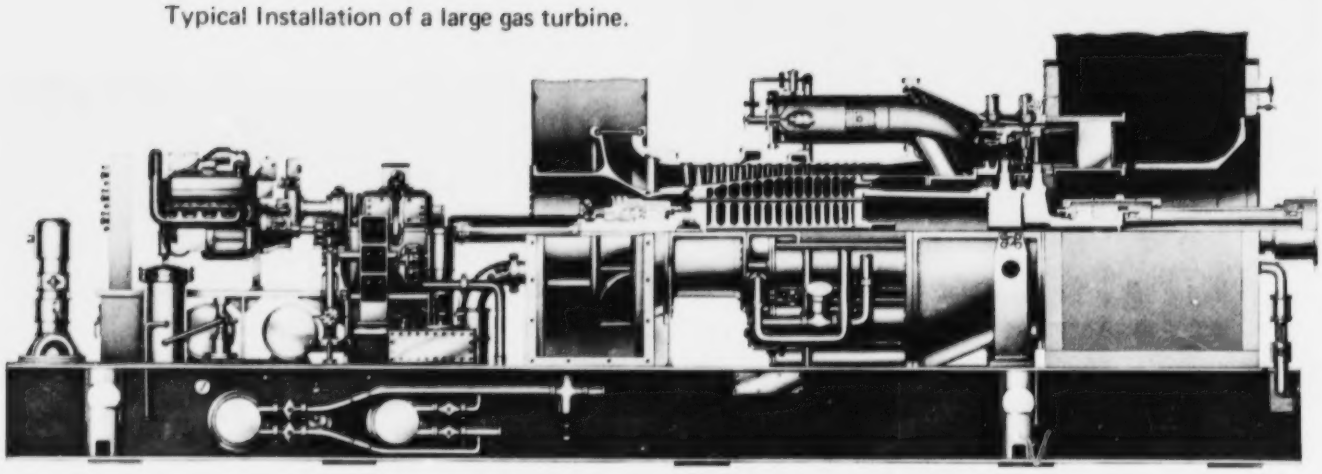

Figure 12.

Multiple Installation of large gas turbines.

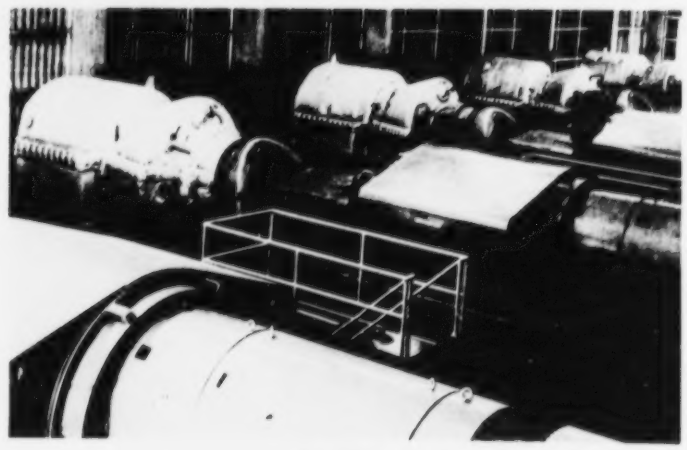

Figure 13.

TURBOELECTRIC SYSTEM. The gas turbine and the electric generator are the major components of the turbo-electric subsystem. Industrial gas turbines have been developed using two different design approaches: machines based on steam turbine experience and those based on jet aircraft experience.

The heavy-duty industrial gas turbines are best suited for the prototype CPU-400 because fewer modifications are required to duct the compressor air to the combustor and back into the turbine. Future production models may accept both types of machines. For the purposes of this brochure, however, only the heavy duty type of industrial gas turbine is described.

A typical large gas turbine has a base load rating of 15 megawatts. It has a high efficiency, 16-stage compressor and a 2-stage impulse turbine mounted on a single shaft. The machine operates at a relatively low speed of 5,100 rpm, hence a single set of gears is required to match the speed with the 3,600 rpm generator.

A wide selection of starting devices is available for the 5,000 series gas turbine. A diesel engine, an electric motor, a steam turbine, or an air turbine can be provided. All turbine auxiliaries, such as the starting system and the oil system, are integrally mounted on the base.

The generator is a 3,600-rpm, 60-cycle, 2-pole machine with a baseload rating of approximately 15 megawatts at 13,800 volts. The generator will have full Class B stator and rotor insulation and a self contained cooling air system.

ADD-ON SYSTEMS

The gas turbine cycle, as planned for the CPU-400, may very well provide energy for add-on systems capable of performing other attractive services to the community while the basic unit incinerates solid waste to produce electricity. These add-on systems, currently in the early phases of development, include: (1) VaCol, automated vacuum collection of refuse; (2) CPU-400S, steam production for heating or air conditioning; (3) CPU-400SW, saline water conversion; (4) CPU-400SB, disposal of sewage sludge.

VaCOL. The vacuum collection system uses underground pipes to connect each dwelling to the system, similar to present-day sewers, and allowing daily collection, which occurs late at night when the demand for electric power is low (Figure 15). Collection is accomplished by automatically sequencing a simple gate valve at the base of each collection chute. The system should be able to collect refuse from 100 to 150 thousand people in a few hours of operation.

The VaCol system has been demonstrated to be technically feasible, and an economic study has shown that collection can be accomplished at less than half of current costs. This is true even when pipes must be installed under existing streets. For model-city programs, even greater savings can be realized.

CPU-400SW. The desalting add-on system can produce 2.5 million gallons of fresh water per day (Figure 16). The plant is designed to use the exhaust heat energy from the gas turbine to power a multistage flash evaporation process. The combined system may be capable of reducing refuse disposal costs to half of their present value while supplying the fresh water at no cost.

CPU-400S. With the addition of a boiler, the heat from the hot exhaust gas leaving the turbines may be used for generating over 82,300 pounds of steam per hour.

CPU-400SB. The basic CPU-400 can readily be adapted for burning sewage sludge. The exhaust heat produced in the unit by incineration of the average resident's daily contribution of 5 pounds of refuse is adequate to dry the sewage sludge produced daily by the same resident. After drying, the sludge can be burned in the combustor to contribute heat to the cycle.

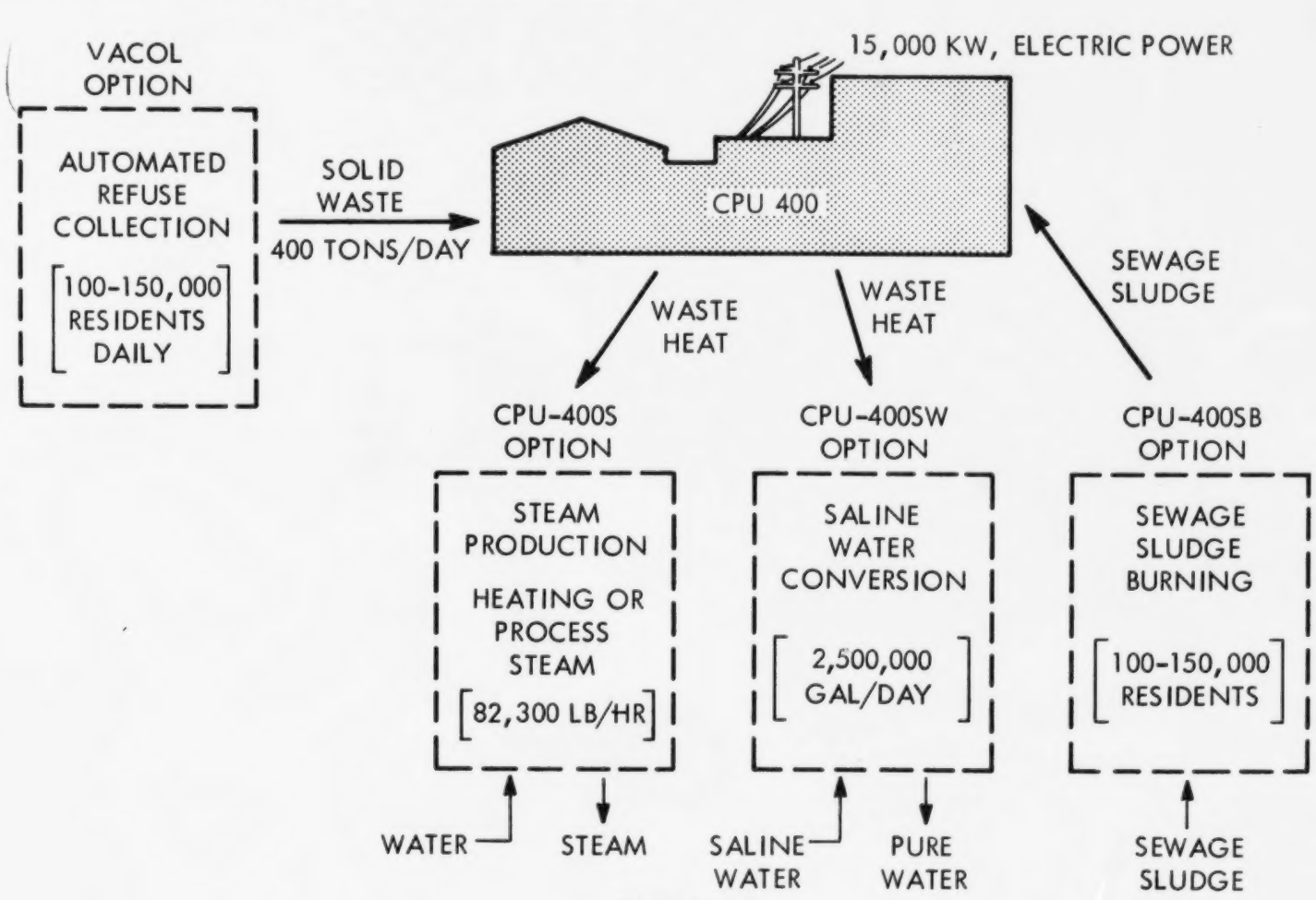

Figure 14.

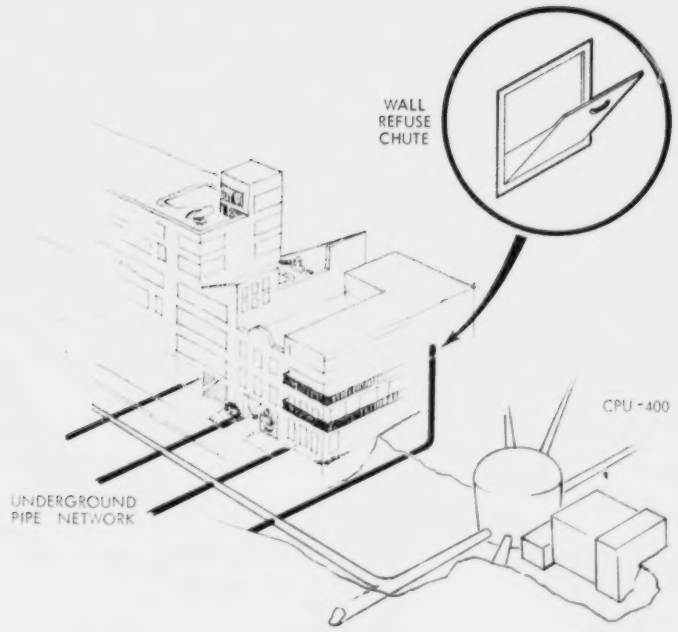

Figure 15.

VaCol utilizes the capability of the CPU-400 gas turbine compressor to draw a powerful vacuum. The large volume, low pressure air flow through underground pipes carries the solid waste to the sealed carousel.

The CPU-400SW plant is approximately twice the size of the basic CPU-400. The brine heater is located in the gas turbine exhaust duct vertically above the turbine; all other desalting equipment is located outside of the basic CPU-400 building.

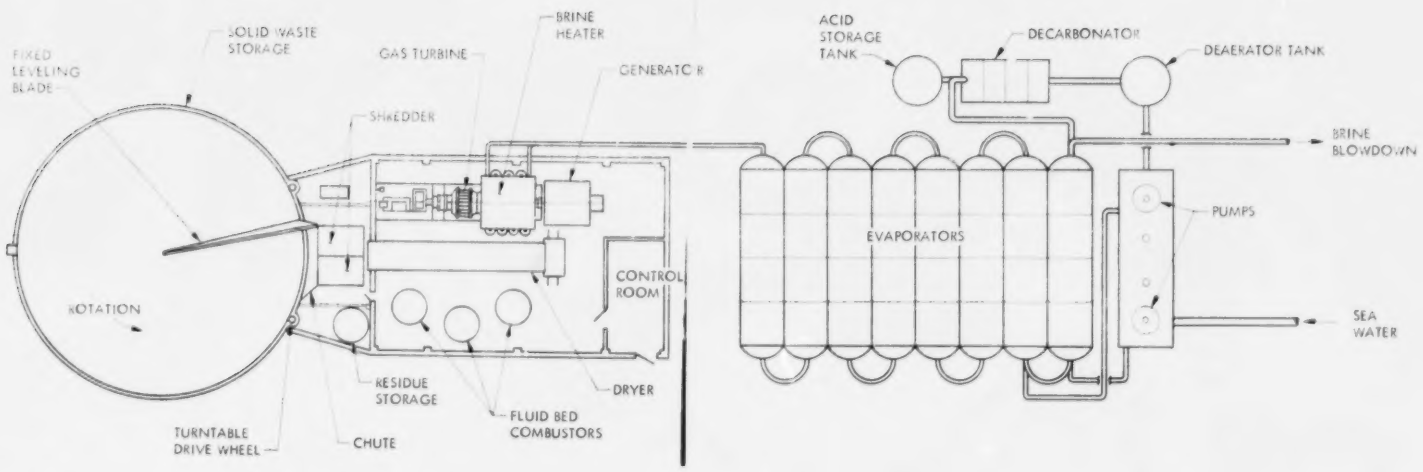

Figure 16.

SUMMARY OF ESTIMATED PERFORMANCE

CAPITAL COST[1]

	MUNICIPAL OWNERSHIP		UTILITY OWNERSHIP
Site preparation and foundations	$ 116,690		
Building and facilities	33,500		
Equipment	3,488,328		
Installation	45,000		
		$3,683,518	
Engineering (7%)		257,486	
		$3,941,004	
Interest during construction		66,997	
Total		$4,008,001	$4,008,001

ANNUAL OPERATING COST[2] (Assuming no income from electric power, steam or residue)

	MUNICIPAL OWNERSHIP[3]		UTILITY OWNERSHIP
Amortization	$260,400		
Insurance	10,000		
Total fixed charges on capital		$270,400	$520,000
Operating labor	$107,000		
Maintenance labor	8,000		
Overhaul	4,500		
Payroll extras	17,900		
G & A	20,600		
Fuel cost	700		
Station power	13,000		
Maintenance supplies	6,000		
Interest on working capital	1,500		
Total plant operating cost		179,200	179,200
Contract maintenance			
Gas turbine	$ 39,000		
Combustor assembly	90,000		
Solid waste subsystem	40,000		
Control system	6,000		
Total contract maintenance		175,000	175,000
Total		$624,600	$874,200
Cost per ton of refuse consumed		$4.27	$5.99

ERRATUM

ANNUAL INCOME

	ANNUAL	$/TON
Electric power only (82% load factor)[4]	$485,000	3.32
Steam only (120 days per year)	$ 68,202	0.47
Combined cycle (120 days of heating, plus 240 days additional electric power from steam)	$693,800	4.75
Residue (saleable by-products)[5]	$120,600	.83

NET OPERATING COST OR PROFIT ($/TON)

PLANT CONFIGURATION	MUNICIPAL OWNERSHIP DISPOSAL COST	UTILITY OWNERSHIP DISPOSAL COST[6]
Electric power only	0.95	2.67
Electric power plus steam	0.48	2.20
Combined cycle*	–0.34	1.38
Electric power plus residue	0.12	1.84
Electric power plus steam plus residue	–0.35	1.37
Combined cycle plus residue*	–1.17	0.56

In addition to the low disposal costs shown, the CPU-400 will provide indirect cost savings in refuse hauling through modular dispersement.

*Adjusted for increased capital cost (0.14/ton).

NOTES:

1. Generous allowances have been included in the performance estimates for those components whose final configuration is not now known but will be determined by the results of early experiments. The cost of the turboelectric generator, the single most expensive component of the CPU-400, is well known.

2. The CPU-400 is designed to be fully automatic, controlled from a single station, such that it can be operated by three men on day shift and two men on swing and midnight shifts. Four crews are required for continuous plant operation.

3. For investor owned utilities, the fixed charges on capital investments are approximately 13 percent as compared to 6.8 percent for municipal ownership. Utilities must pay higher interest rates, pay taxes, and provide a return for their stockholders.

4. A representative, yet conservative estimate for the average value of the electric power produced by the CPU-400 is assumed to be 4.5 mils per kilowatt hour.

5. The CPU-400 will produce 80 tons per day of clean, sterile residue. Income from the sale of this residue is based on an estimated average value of $2.00 per ton for medium ash, $3.00 per ton for coarse ash, and $10.00 per ton for coarse ferrous residue.

6. For utility ownership, the cost per ton for disposal of the refuse would be paid by the city.